FEASIBILITY STUDY
FOR LEAD REMOVAL
FROM AND STRUCTURAL RESTORATION OF
CRUISER, OHIO, AND LOS ANGELES CLASS
REACTOR COMPARTMENT
DISPOSAL PACKAGES

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EXECUTIVE SUMMARY

The Navy has performed feasibility studies for the removal of permanently installed shielding lead from cruiser, LOS ANGELES, and OHIO class reactor compartments that are being considered for disposal at the Department of Energy's (DOE) Hanford site.

LOS ANGELES and OHIO Class submarines have one reactor compartment. Nuclear cruisers have two reactor compartments. It is estimated that the cost to remove the several hundred tons of shielding lead from these packages would be between $16 and $108 million per reactor compartment in fiscal 1994 dollars. The personnel who would perform this work at Puget Sound Naval Shipyard would be exposed to an additional radiation exposure of approximately 585 rem to 1065 rem per reactor compartment. For comparison, all other reactor compartment packaging work would not be expected to exceed 20 rem of radiation exposure per package. The total radiation exposure to the Shipyard workforce performing the lead removal operations is estimated at approximately 90,000 rem for the approximate 100 reactor compartments.

For comparison, this estimated radiation exposure (90,000 rem) is almost double the radiation exposure the entire Naval Nuclear Propulsion program received in the ten years from 1982 to 1992. Additionally, if a total radiation exposure of 90,000 rem were received over the span of a lead removal program, there might be an additional 36 fatal cancers in the lifetime of a typical group of 10,000 persons. This additional radiation induced cancer risk to the workers outweighs any potential environmental benefit in reusing part of the removed lead.

An equally important aspect in addition to the radiation exposure is that approximately 25% of the lead removed would remain radiologically controlled due to neutron activation of the impurities within the lead. This lead would have to be encapsulated and packaged for land disposal as mixed waste. The estimated quantities of shielding lead, costs for removal, and radiation exposure for shielding lead removal from the ship classes considered are summarized in Table A.1. Thus, both the expense and additional radiation exposure for shielding lead removal would be substantial and prohibitive. The subdivision alternative, unlike the preferred alternative, would not require the structural integrity of the reactor compartment to be maintained to meet shipping requirements, so it would result in easier lead removal.

1. INTRODUCTION

The Navy's 1984 Environmental Impact Statement (EIS) discussed the disposal of decommissioned, defueled naval submarine reactor plants. Since the disposal of lead was not controlled by Federal or State regulations at that time, disposal of lead radiation shielding was acknowledged without special precautions in the Navy's 1984 EIS.

Currently, the shielding lead in the submarine packages is not regulated under the Federal Resource Conservation and Recovery Act since the shielding is still serving its intended purpose and thus is not waste. In 1989, the State of Washington Department of Ecology determined that this lead is a regulated waste under the state's Hazardous Waste Management Act (RCW 70.105.050). This Act requires:

> Prior to disposal, or as part of disposal, all reasonable methods of treatment, detoxification, neutralization, or other waste management methodologies designated to mitigate hazards associated with these wastes shall be employed, as required by applicable federal and state laws and regulations.

In 1990, a shielding lead removal feasibility study provided information to the State of Washington on the disposal of the several hundred tons of permanently installed lead shielding that is contained within the welded steel plates and structure of each reactor plant packaged under the submarine disposal program described in the 1984 EIS.

The cruiser, LOS ANGELES, and OHIO class reactor compartment packages would continue to consist of the section of the ship containing the reactor compartment. For cruisers, the reactor compartment would be cut from the ship and a thick steel outer package installed around and welded to the reactor compartment to produce a strong, tightly sealed containment. The current submarine packaging methodology of closing the ends of the submarine hull with welded steel bulkheads would be applied to the LOS ANGELES and OHIO classes. The configurations of cruiser and submarine reactor compartment packages are essentially various sizes of vertical or horizontal cylinders respectively, with the exception of the USS LONG BEACH (CGN-9), which would be a rectangular box. The packaging for these reactor compartments would be designed to meet all regulatory requirements for transport of radioactive materials.

This report contains the results of the shielding lead removal feasibility study for reactor compartment packages from the cruiser, LOS ANGELES, and OHIO classes. The quantity of shielding lead involved, cost for removal, personnel radiation exposure, and occupational risks to workers performing the shielding lead removal tasks are presented.

2. DESCRIPTION OF SHIELDING LEAD CONTAINED IN REACTOR COMPARTMENT PACKAGES

2.1 Permanent Shielding Lead

Shielding is installed to satisfy three functions:

1. To reduce gamma and neutron radiation from the reactor and reactor coolant system to safe levels outside the reactor compartment during operation.

2. To reduce radiation from core fission products and primary shield activation to safe levels for access to the reactor compartment and system tanks after plant shutdown.

3. To reduce neutron activation of materials in the reactor compartment.

There are four separate permanent shielding systems installed on nuclear cruisers and LOS ANGELES and OHIO class submarines to accomplish the above functions:

1. The primary shield which encompasses the reactor vessel itself.

2. The secondary shield which encompasses the primary plant components and the majority of the associated piping (Figure A.1).

3. Primary and secondary shielding above and beneath the reactor vessel.

4. Individual component shielding.

Shielding design is generally the same for each class of surface ship or submarine reactor plant. Steel plates cover the shielding lead to maintain its position and prevent abrasion or damage. For further strength, the majority of shielding lead is permanently bonded to the structure and components during construction.

2.2 Miscellaneous Lead

Cruiser, LOS ANGELES, and OHIO class reactor compartment packages would contain relatively small quantities of lead bound in the matrices of paint, glass, adhesives, brass and bronze alloys and numerous other industrial materials used in the construction of components and equipment. The average quantity of lead in these reactor compartment packages is estimated at less than 450 kilograms (1,000 pounds) per package. Since this quantity of lead is small with respect to the total quantity of shielding lead in a reactor compartment package, it is not considered further in this study.

2.3 Considerations

In the development of methods for shielding lead removal, several requirements were given primary consideration, specifically maintaining the structural integrity of the existing ship's structure in order to facilitate conversion to a reactor compartment package, compliance to the Code of Federal Regulations transportation requirements of 10CFR71, and the long term integrity of the reactor compartment package for containing the radioactive and hazardous material. The removal of permanent shielding lead as described in this report would require the removal of a significant quantity of structural interferences. All critical structure to be removed is considered to be reinstalled to full strength.

A significant effect of shielding lead removal is the resultant increase in package exterior radiation levels. Calculations indicate that after the removal of shielding materials, localized contact radiation levels on the exterior of the reactor compartment package would be above the Code of Federal Regulations transportation limits, section 10CFR71.47. These localized high contact radiation levels could be reduced by installing additional steel shielding plates. Other package contact radiation levels, although increased because of shielding removal, would comply with the Federal transportation limits.

2.4 Assumptions

While this study evaluates the methods, costs, and radiation exposure required for a large scale lead removal program, it does not consider in detail some of the practical issues that actual implementation of such a program would entail. For example, lead removal work would occupy shipyard drydocks for long periods of time, which would displace other ship maintenance work. Significant shipyard labor force disruptions would be caused by the large increase in the number of lead and radiation workers combined with the reduction in ship maintenance work displaced by the lead removal work. The costs involved with issues such as training and qualification of new personnel and procurement of required materials and equipment, were incorporated into the overall shielding lead removal cost estimate. Table A.1 summarizes the result of these estimates for the nuclear cruiser, LOS ANGELES, and OHIO classes.

3. SHIELDING LEAD REMOVAL PREPARATIONS

3.1 Training

Puget Sound Naval Shipyard has considerable experience in removing small quantities of permanently installed shielding lead and employs a sufficient number of radiologically qualified lead workers to accomplish the shielding lead removal work. During current overhaul, reactor compartment packaging, and hull recycling work, this Shipyard processes an average of 45 tons of shielding lead using radiological controls. This process involves controlling the lead as a potentially radioactive material until an evaluation of the lead can be made to determine whether the lead can be released from radiological controls. The evaluation involves a combination of surface radiation and activity measurement and in some cases, internal activity determination by analyzing gamma radiation emission (requires reducing removed lead into relatively small chunks of 9 kilograms (20 lbs) or less). Due to the large quantity of shielding lead described in this report, the existing group of radiologically trained lead workers would be insufficient to undertake a shielding lead removal project of this magnitude.

In addition to basic skill qualification training, special mock-up training would be required prior to commencement of critical work evolutions in high radiation and shielding lead removal areas. This training, which utilizes mockups of the actual components and structures, has proven effective in reducing worker exposure to radiation and hazardous materials. Job skills, qualification testing, tooling, and instructions are rehearsed and verified before accomplishment of the actual work. The costs associated with this mockup training for shielding lead removal have been factored into the cost estimates, Table A.2.

3.2 Interference Removal

Naval ship design inherently attempts to minimize the overall size of the spaces within the ship. Designers attempt to utilize the available space to its maximum extent. Access to areas not requiring routine maintenance, in most cases, was a secondary consideration and in some cases, no access was provided. Permanently installed shielding lead is often located beneath interfering components (e.g., cabling, piping, deck gratings, hangers and equipment foundations) and large reactor plant equipment (e.g., steam generators, pressurizers, and reactor coolant pumps). Additionally, significant quantities of asbestos from ships constructed during the 1950's and 1960's and radioactively contaminated interferences would require removal. These latter interferences pose a significant personnel health hazard which will be discussed elsewhere in more detail. Interference removal therefore would be a major expense and has been factored into the shielding lead removal cost estimates of Table A.2.

3.3 Shielding Lead Removal Techniques

The following discussion describes the most practical method for Puget Sound Naval Shipyard to remove the permanently installed shielding lead (up to 99% removal) while attempting to minimize personnel exposure (lead and radiation). The discussion is general in nature but provides sufficient detail to establish an understanding of the magnitude of the work involved. Work prerequisites, such as standard interference removals, radiation containment tent installations, etc., are routinely accomplished in the Shipyard. They are not included in these descriptions unless necessary to emphasize the complexity of a particular task.

3.4 Removal of Shielding Lead Bonded to Structure

Shielding lead is generally metallurgically bonded to the reactor compartment structures in varying thicknesses and sizes and is covered by steel plate. In order to minimize structural degradation of the reactor compartment package, the following method of shielding lead removal was selected. The welds on the steel plate covers would be cut by carbon arc gouging and the plates removed. After the lead is exposed, it would be melted from the structure using hand torches in a controlled environment or enclosure to reduce lead and radioactive contamination to the workers. All removed materials would be transported to a controlled storage building for radiological survey and segregation and, if possible, released from radiological controls.

In some locations polyethylene neutron shielding is collocated with the lead shielding. For fire prevention, some of the polyethylene shielding will require removal before hot lead removal work can be done in the immediate vicinity.

Normal reactor compartment packaging work already removes some of the items interfering with access to shielding lead, therefore additional interference removal for shielding lead work in these areas would be minimized. However, removal of some additional piping and components adjacent to the reactor compartment structure would be required. Some of these systems are radioactively contaminated and require special controls during their removal.

The removal of shielding lead that is metallurgically bonded to structures is complicated when this lead is installed in geometrically complex arrangements, behind surfaces covered by asbestos thermal insulation, and in areas with loose and fixed radioactive contamination. Lead removal under these conditions would require an elaborate lead burning and radioactive contamination containment tent. Some items would be disassembled and disposed of separately, such as the reactor compartment leaded glass viewing window assembly by removing the shielding leaded glass from the Lucite and plate glass. In horizontal areas, the shielding lead would be removed by melting with hand torches and allowing the molten lead to drain through holes that are either melted or drilled through ship's structure. Collection pans would be placed directly beneath the drain holes to catch the molten lead or temporary troughs would be placed to direct the molten lead laterally into collecting pans. An elaborate scaffolding system would be required inside the reactor compartment to support the lead collection equipment, to allow adequate personnel access, and support the containments necessary for lead vapor control. After completion of shielding lead removal, residual shielding lead would be removed using chipping or grinding within containment tents. In order to restore integrity in some structures, key structural stiffeners would be repaired. This would necessitate lead free cleanliness requirements in localized areas prior to rewelding.

Some shielding lead was installed prior to the installation of major plant equipment. Removal of this equipment is impractical while maintaining the reactor compartment structural integrity. An elaborate combination of partial foundation removal, installation of temporary supports, and lead removal techniques would be required.

In order to maximize the advantages of the existing shielding lead in reducing personnel radiation exposure, some shielding lead removal operations would be deferred until relatively late in the packaging sequence, tending to increase costs due to re-setup of equipment and containments.

3.5 Removal of Component Shielding

Several components of reactor plants are shielded with a combination of portable and permanently installed shielding lead. To remove the components from the reactor compartment package for separate disposal, the portable shielding, which is an interference to the component's removal, would be removed first. The component would then be removed from the package and the component's permanent shielding lead removed using melting and/or chipping. For some components, residual amounts of internal fluids would also have to be removed or adsorbed prior to disposal.

Finally, some component foundations incorporate shielding lead which would require removal, or replacement, of the foundation in the reactor compartment package. Once removed, the foundation shielding lead can be further segregated prior to disposal

4. DISPOSAL OF REMOVED MATERIALS

The generation of radioactive waste is an unavoidable byproduct of the disposal work on Naval Nuclear reactor plants. Radioactive waste materials, generated by work on contaminated ship's systems or by removal of activated and/or contaminated components, would be containerized and shipped to licensed radioactive waste burial sites. Burial sites for low level wastes have limited capacity; therefore, every effort is made to ensure the volume of disposed radioactive waste is kept as small as practicable.

Puget Sound Naval Shipyard has established a solid waste minimization program to reduce the volume of radioactive waste. At the center of this program is the concept of waste segregation. Waste is segregated at the worksite into one of three categories: non-contaminated, potentially contaminated, or known contaminated. Radiological surveying resolves the potentially contaminated category by reclassifying it as either known contaminated or non-contaminated. All known contaminated waste would be disposed of as radioactive waste while non-contaminated waste would be disposed of in accordance with State and Federal regulations.

Waste quantity is also reduced by recycling materials to the maximum extent practicable. Recycling consists of techniques such as reusing tools and laundering anti-contamination clothing.

It is anticipated that over 75 % of the shielding lead removed from each reactor compartment package would be released from radiological controls and recycled through the Defense Reutilization and Marketing Office. However, some shielding lead may have impurities which have become activated due to neutron activation. Decontamination of this lead by removal of radioactive impurities would not be practicable because lead used in reactor shielding already is high purity lead which was refined an extra step to minimize impurities. This lead would need to be stored in accordance with the Site Treatment Plan as a mixed waste for eventual disposal, since, lead cannot be released from radiological controls. Radioactive lead must be disposed of as mixed waste, since shielding lead is also regulated as a dangerous waste by Washington State regulations. These regulations require that disposal of mixed waste be at an approved disposal site. There are presently no disposal sites authorized to accept mixed waste.

The fact that much of the lead would require radioactive disposal after removal from the reactor compartment eliminates much of the potential benefit of removing the lead. The shielding lead is well encapsulated in the reactor compartment package. Little is accomplished in removing the lead at considerable risk to workers and expense if much of the lead must then be reencapsulated and buried somewhere else.

5. PERSONNEL HEALTH AND SAFETY HAZARDS

5.1 Personnel Exposure to Lead

Pure lead is a solid heavy metal at standard atmospheric conditions. It can combine with various substances to form numerous lead compounds. Lead in its various forms may enter the body by being swallowed, inhaled, or absorbed through the skin.

Lead may be swallowed by eating contaminated foods, smoking or chewing contaminated tobacco products, licking of lips, or placing fingers in the mouth. Lead absorption can be the result of neglecting to cleanse the hands and/or face thoroughly before eating, drinking, or smoking. However, these pathways would not be considered common place based on the occupational safety controls employed at the Shipyard.

Lead may be inhaled as lead fumes from heated lead or leaded materials; as mists from lead-pigmented paints; as dust from abrasive blasting, caulking, machining, grinding, sawing, sanding, scraping, or filing of lead or leaded materials; or as vapors from volatile lead compounds such as tetraethylene lead or lead paint dryers. Lead exposure by inhalation of particles or vapors from the melting, chipping, and scraping removal process described in this report would be the most common form of exposure.

Lead workers and supervisors must be trained in work involving lead hazards, enrolled in Puget Sound Naval Shipyard's medical surveillance program, and be respirator qualified.

The highest level of lead in the air to which a worker may be exposed over an eight hour workday is 50 micrograms per cubic meter of air (50 $\mu g/m^3$) and is called the Occupational Safety and Health Act (OSHA) permissive exposure limit (PEL). Lead melting operations described in this study have produced unfiltered air concentrations up to 5500 $\mu g/m^3$ in an eight hour (time weighted average) period at Puget Sound Naval Shipyard. The use of protective clothing, air supplied respirators, engineered controls, and containment tents, allows Shipyard personnel exposures to be kept below the OSHA requirements when exposed to these airborne lead levels.

5.2 Personnel Exposure to Asbestos

In order to conduct shielding lead removal from reactor compartment packages, asbestos containing items, such as lagging, must first be removed as interference. Several controls are used to prevent personnel exposure to airborne asbestos during asbestos removal. First, asbestos removal operations are accomplished by employees of Puget Sound Naval Shipyard who are both medically qualified and trained in the proper asbestos handling and removal control processes. Second, to control the release of asbestos fibers, processes would be used that include engineered High Efficiency Particulate Air (HEPA) filtered negative exhaust ventilation systems, asbestos wetting, HEPA filtered industrial vacuum cleaners, containment tents, and containment glovebags. Third, following asbestos removal, Puget Sound Naval Shipyard's Occupational Safety and Health Office would conduct post clean-up certifications, including air sampling and visual inspections, prior to releasing the space for unprotected personnel access.

5.3 Personnel Exposure to Ionizing Radiation

Control of radiation exposure in the Naval Nuclear Propulsion Program has always been based upon the assumption that any radiation exposure, no matter how slight, involves some risk. However, radiation exposure within the accepted exposure limits, as promulgated by federal regulations, represents a small risk compared with the normal hazards of life.

Current federal regulations allow personnel beyond 18 years of age to receive a whole body penetrating radiation dose of 5 rem for each year of a persons life over age 18. The Navy has established more restrictive limits for individuals receiving radiation exposure from the Naval Nuclear Program. Normal local exposure control level for Shipyard personnel is 0.5 rem per calendar year. In some rare cases, it is necessary for selected personnel, due to their trade skills, to exceed this local control level. In these cases, local control levels may be incrementally increased up to but not exceeding 2 rem per calendar year. The Navy has established these limits as a commitment to maintain radiation exposure to personnel as low as reasonably achievable.

During reactor compartment package preparation work, exposure to gamma radiation is generally limited to the vicinity of the reactor plant. The principle source of this gamma radiation is Cobalt-60 activity. Cobalt-60 has a half-life of 5.27 years, which means that the total quantity of Cobalt-60 activity decreases by a factor of two every 5.27 years. Other radionuclides present in the compartments either do not emit gamma radiation, such as nickel-63 which emits a short range beta particle, or if gamma radiation is produced, the radionuclides are present in much smaller activities than Cobalt-60 and have much shorter half-lives.

In determining how to remove permanently installed shielding lead, techniques were primarily considered which would minimize personnel radiation exposure. This included sequencing shielding removal to utilize the benefits of the primary shield as long as possible. Because of the proximity to the reactor vessel during significant amounts of lead removal work, personnel exposure to high radiation fields will require restrictive radiological controls to ensure adequate protection. The amount of time workers can spend in high radiation fields of the magnitude expected and not exceed Shipyard control levels for radiation exposure is unacceptably short. To further complicate lead removal work, physical constraints can preclude the use of temporary shielding.

Immediate removal of all permanently installed shielding lead from the reactor compartment package and installation of a permanently installed steel shield package, to reduce package external radiation levels, would result in an estimated radiation exposure of approximately 585 rem to 1065 rem per package. This rem estimate is based upon; (1) reducing radiation levels within the reactor compartment during work by installing temporary shielding; and (2) applying the estimated mandays during which workers are subjected to this reduced exposure.

6. RADIOLOGICAL AND ENVIRONMENTAL CONTROL REQUIREMENTS

Because most work would be accomplished in radiation or high radiation areas, and some work would involve loose surface and/or fixed radioactive contamination, radiological controls would be required for the various shielding lead removal operations.

A large containment structure would be required to enclose each reactor compartment package. This structure would serve several functions. Work inside this structure would be accomplished primarily using smaller temporary containment structures with HEPA filtered exhausts to control radioactive contamination to ensure adequate personnel and environmental protection from the shielding lead removal operations. In addition, for work in a controlled surface contamination area, portable air samples would be taken at the start of work and every four hours thereafter until work is complete. The reactor compartment containment structure may consist of several smaller units since the largest single containment necessary would exceed 13 meters (42 feet) in height and 17 meters (55 feet) in length.

In addition to radioactive and hazardous material containment structures, support facilities and services (e.g., air conditioning, lead vapor filtration, negative ventilation, personnel changing and shower facilities, temporary controlled material storage facilities, separate controlled work areas that would allow segregation and disassembly of components removed from the reactor compartment, personnel access and weight handling support structures, etc.) would be required for this work. The specifics of these requirements are not discussed in this study, but have been factored into the cost estimates of Table A.2.

7. FINDINGS

7.1 Costs

The estimated shielding lead removal costs for the nuclear cruiser, LOS ANGELES, and OHIO classes, based on mandays for Puget Sound Naval Shipyard's organization, are summarized in Table A.1 and listed by each type of reactor compartment in Table A.2. The costs vary from $16 million for OHIO class submarines to $108 million for the cruiser USS LONG BEACH (CGN-9).

7.2 Radiation Exposure

Of greater importance than cost is the additional personnel radiation exposure of approximately 585 rem to 1065 rem per reactor compartment package. For comparison, all other reactor compartment packaging work combined is not expected to exceed 20 rem of radiation exposure per package. This large personnel radiation exposure for shielding lead removal could not be accommodated by the relatively small lead/hazardous materials qualified workforce available at Puget Sound Naval Shipyard. Retraining a large part of the Shipyard workforce for qualification in removing lead/hazardous materials is expected to increase the total number of Shipyard radiation workers. The lead workers would not be available for other radiation work due to these personnel reaching annual radiation exposure control levels.

A brief description of the effects of exposure to radiation would help understand why this is important. The total radiation dose received by the Shipyard workforce is estimated at 90,000 rem to support lead/hazardous material removal. To place this radiation exposure into perspective, the dose received by all Navy and civilian personnel associated with Naval Nuclear Propulsion in the ten years from 1982 to 1992 was approximately 50,000 rem. The combined total of Navy and civilian personnel monitored for radiation exposure for those ten years was slightly less than one million people. To comply with the maximum individual radiation exposure control level of 2.0 rem per year established by the Navy, Puget Sound Naval Shipyard would need a dedicated workforce of at least 4500 employees to support the lead/hazardous material removal effort for a 10 year program. This would be a significant portion of the entire shipyard production workforce presently employed at Puget Sound Naval Shipyard.

The risk associated with exposing these shipyard employees to radiation dose can be evaluated by utilizing risk assessment guidelines established by the International Commission on Radiation Protection. The Commission established a method to assess the risk by comparing exposure to only natural background radiation to exposure to additional industrial radiation. The average annual dose received by a member of the population in the United States from natural background radiation is approximately 0.3 rem, with a average annual collective dose of 69 million person-rem to the entire population.

In a typical group of 10,000 persons who are exposed only to natural background radiation, about 2000 (20 percent) will normally die of cancer. If each of the 10,000 persons received an additional 1 rem of industrial radiation exposure in their lifetime, an estimated 5 additional cancer deaths might occur (2005 total cancer fatalities).

To be consistent with the Commissions analysis, assume that this 90,000 rem is evenly distributed to a workforce of 10,000 employees (90,000 person-rem). The risk factor published by the Commission for fatal cancers to workers is 0.0004 per person-rem. Therefore, there might be an additional 36 fatal cancers in the lifetime of a typical group of 10,000 persons associated with a total radiation exposure of 90,000 rem.

The analysis of this feasibility study has focused on the costs and effects from lead removal activities performed shortly after the ship has been decommissioned, typically less than 5 years after decommissioning. The effects from delaying this work for an extended period of time after decommission, such as 5 years, 10 years, and 15 years, are briefly discussed here.

Worker radiation exposure for lead removal would result in increased worker dose for the preferred alternative but is already factored into the dose estimates for the subdivision alternative. The radiation levels within the reactor compartments should decrease by a factor of 2 every 5.27 years, based on the half-life of Cobalt-60. Worker radiation dose would be reduced by delaying operations. This effect is shown in Table A.1.

The cost of lead removal activities is also provided in Table A.1. Lead removal would be an added cost for the preferred alternative of land burial at Hanford but is already factored into the cost for the subdivision alternate. Delaying the work would not significantly affect the estimated man-hours utilized to determine the total cost in Table A.2 because the work would still require radiological controls and lead controls. However, the overall cost is expected to increase. The amount of increase is difficult to estimate but should be bounded on the lower end by the rate of inflation for the delay period.

The cost to remove lead in conjunction with the preferred alternative would be comparable to the cost to remove lead as an integral part of the subdivision alternative. The subdivision alternative, unlike the preferred alternative, would not require the structural integrity of the reactor compartment to be maintained to meet shipping requirements, so it would result in easier lead removal. However, the quantity of lead, its general configuration and the basic removal techniques would be the same in each case plus radiological controls and lead controls would still be required. These factors would result in similar costs. Radiation exposure to workers would also be comparable for the preferred alternative and the subdivision alternative for the same reasons.

8. CONCLUSION

The removal of several hundred tons of shielding lead from cruiser, LOS ANGELES, and OHIO class reactor compartment packages is estimated to cost in fiscal 1994 dollars between $16 million and $108 million per reactor compartment package.

The total radiation dose receiving by Shipyard personnel performing the lead/hazardous material removal operations is estimated to be up to 90,000 rem. This is almost double the radiation exposure received by all Navy and Shipyard personnel for the ten years from 1982 to 1992. It has been estimated that 90,000 person-rem might result in 36 additional fatal cancers in the lifetime of 10,000 people.

About 25% of the lead removed from the reactor compartment disposal packages would not be released from radiological controls, resulting in large quantities of mixed waste to be encapsulated and packaged for land disposal.

The costs, radiation exposure, and also environmental risks to personnel associated with the removal of shielding lead from cruiser, LOS ANGELES, and OHIO class reactor compartment packages are substantial and prohibitive. A similar conclusion was reached in 1990 for the pre-LOS ANGELES class reactor compartment packages prepared under the current submarine disposal program.

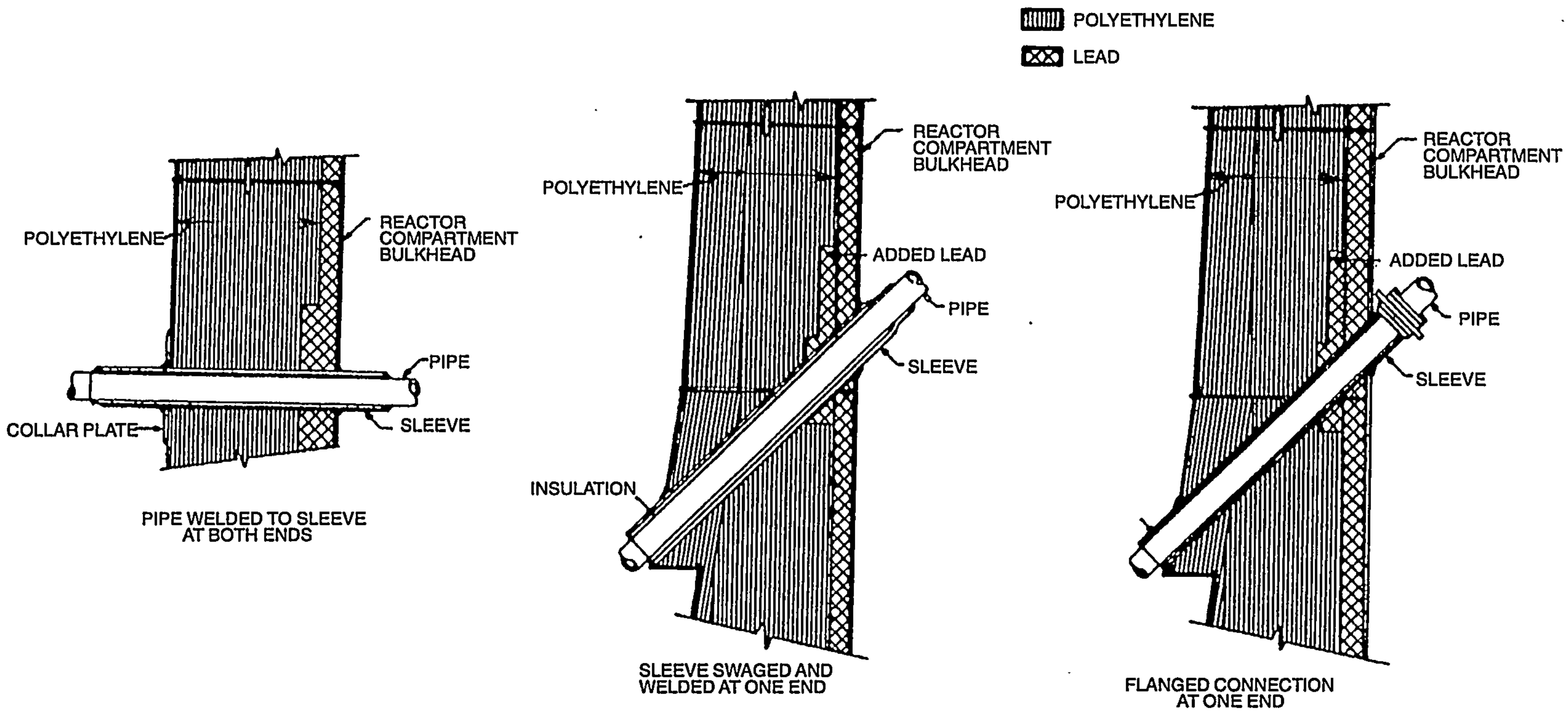

Figure A.1 Typical Small Piping Penetration

	LOS ANGELES CLASS SUBMARINES	OHIO CLASS SUBMARINES	D2G CRUISER[1]	LONG BEACH CRUISER
QUANTITY	>100 tons	>100 tons	>100 tons	>100 tons
COST	$18M	$16M	$29M	$108M
RADIATION DOSE (REM)				
No Delay	1065	585	680	750
5 year Delay	552	303	352	389
10 year Delay	286	157	183	201
15 year Delay	148	81	95	104

NOTE: The above estimates are based on an engineering evaluation of the required removal efforts. Cost and radiation dose estimates were developed from summaries of the required removal efforts. Radiation dose estimates were developed utilizing radiation fields expected to be typical of the reactor plant being evaluated. Costs are based on using Puget Sound Naval Shipyard's current (FY94) rates.

1: BAINBRIDGE, TRUXTUN, CALIFORNIA Class, and VIRGINIA Class

Table A.1 Lead Removal Estimate Summary (per reactor compartment)

D2G CRUISERS

Engineering Services	8,840
Radiological Control Services	6,234
Production Services	31,794
TOTAL Man-days	46,868
TOTAL COST (including material)	$28,840,300

1: BAINBRIDGE, TRUXTUN, CALIFORNIA Class, and VIRGINIA Class

LOS ANGELES CLASS SUBMARINES

Engineering Services	6,008
Radiological Control Services	4,005
Production Services	26,863
TOTAL Man-days	36,876
TOTAL COST (including material)	$18,300,000

OHIO CLASS SUBMARINES

Engineering Services	5,143
Radiological Control Services	3,396
Production Services	22,726
TOTAL Man-days	31,265
TOTAL COST (including material)	$15,600,000

LONG BEACH CRUISER

Engineering Services	27,418
Radiological Control Services	18,107
Production Services	89,904
TOTAL Man-days	135,429
TOTAL COST (including material)	$108,196,150*

* Magnitude of estimate due to extensive shielding of package

Table A.2 Lead Removal Cost Estimates (per reactor compartment)